Course on Energy Economics

Market Design and Market Structure in Wholesale Electricity Markets

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Roadmap

Market Design

- **Bid format**
  - multi-units: the number of admissible steps
- **Bid duration**
  - short-lived bids (hourly bids)
  - long-lived bids (one bid for the whole day)
- **Price setting rule**
  - uniform pricing (single market price)
  - discriminatory pricing ("pay as bid")

Market Structure

Multiple Units (symmetric costs within a firm)

Fabra, von der Fehr and Harbord (Rand, 2007)

- All units belonging to the same firm have the same marginal costs.
- Suppliers submit upward-sloping step supply functions:
  - price-quantity pairs (b_{in}, k_{in}), $n = 1, ..., N_i$, $N_i < \infty$ and $\sum_{n=1}^{N_i} k_{in} = k$.

All previous results remain unchanged!

Lemma

In the uniform-price auction, the set of (pure-strategy) equilibrium outcomes is independent of the number of steps in each supplier's bid function (in particular, whether $N_i = 1$ or $N_i > 1$).

Multiple Units (symmetric costs within a firm)

- (Low demand) If $\theta \leq k$, the equilibrium price is c.
  - Argue by contradiction and suppose $p > c$: as none of the firms is producing at capacity, each could achieve an **increase in output** by **marginally undercutting the rival's bid**.
  - As the price reduction can be made arbitrarily small, deviating is profitable.
- (High demand) If $k < \theta < 2k$, the equilibrium price is P.
  - **Asymmetric bidding**: firm i produces at capacity and firm j serves the residual demand. Otherwise, either firm could profitably deviate (same logic as above).
  - Firm i's bids are irrelevant, as long as these are **low enough**.
  - Firm j's bids are irrelevant, as long as there is a sufficiently **large mass of units at** P for the market price to equal P.

Multiple Units: Empirical Evidence

Hortacsu and Puller (Rand, 2007)

In practice, firms do not effectively use all admissible steps in their bid functions.

"The bid rules [in the spot market for electricity in Texas] *allowing 40 price-quantity points afford generators a large degree of flexibility in bidding. However, none of the bidders make full use of the 40 bidpoints that they can use to trace out their optimal bidding functions.* [...] *The firm earning the greatest fraction of ex-post profits (Reliant) also uses the largest number of bidpoints, averaging 22.2 points per bid schedule. None of the other firms use more than 13 points on average."*

Infinite versus Finite Number of Bids

Wilson (1979), Back and Zender (1993)

Assume continuously differentiable bid functions, i.e. $N_i = \infty$.

- There exists a **continuum of pure-strategy equilibria**, some of which result in very low revenues for the auctioneer.
- Participants offer **very steep supply functions** which inhibit competition:
  - Faced with a rival's steep supply function, a supplier's incentive to price more aggressively is offset by the large decrease in price (**'price effect'**) that is required to capture an increment in output (**'quantity effect'**).
  - The 'price effect' outweighs the 'quantity effect' for **units of infinitesimal size.**
  - Hence, extremely collusive-like equilibria can be supported.
- This does not occur when **bids are discrete** since a positive increment in output can always be obtained by just slightly undercutting the rival's price.

The Number of Admissible Steps: Policy

- Does limiting the number of allowable bids improve market performance?
- We have shown that:
  - Moving from a **continuous** to a **discrete-bid** auction potentially improves market performance by eliminating the **'collusive-like' equilibria**.
  - Market performance in a discrete-bid auction is **independent of the number of allowable bids**, so long as this number is finite.
- Hence, since **limiting the number of bids** does not effectively restrict agents' opportunities, it might be desirable in the interests of **market simplicity** and **transparency**.
- [Note of caution: here we are assuming a unique marginal cost]

Multiple Units (asymmetric costs within a firm)

García-Díaz and Marín (IJIO, 2003); Fabra and de Frutos (EER, 2010)

- The units belonging to the same firm **need not** have the same marginal costs.

Example

- $N = 2$; each firm has three production units with MC $\{0, 1, 2\}$
- Inelastic demand, $D = 3$

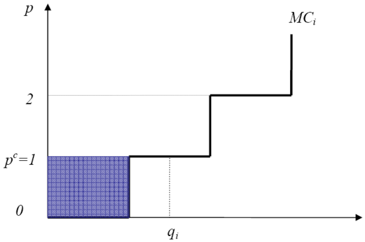
Competitive outcome:

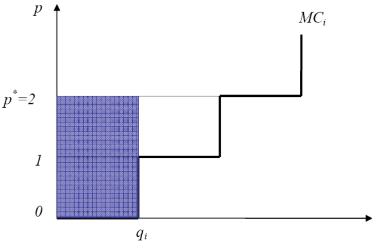
- Suppose both firms bid at MC, $b_i = \{0, 1, 2\}$, $i = 1, 2$
- The aggregate bid function is $B = \{0, 0, 1, 1, 2, 2\}$
- So that $p^c = 1$, $q_i^c = 3/2$ and $\pi_i^c = 1$.

Multiple Units: Example

- The competitive outcome **cannot be sustained** in equilibrium:
  - If $b_2 = \{0, 1, 2\}$, firm 1 responds $b_1' = \{2, 2, 2\}$
  - The aggregate bid function is $B' = \{0, 1, 2, 2, 2, 2\}$
  - So that $p^* = 2$, and $q_1 = 1$, $q_2 = 2$.
  - Profits are $\pi_1 = 2 > \pi_1^c$ and $\pi_2 = 3$.

The Competitive Outcome Cannot Be Sustained





Multiple Units: Equilibrium Bidding

Price-setter:

- Note that $p^* = 2$ is firm 1's profit-max. price given $b_2 = \{0, 1, 2\}$:

$$\pi_1(p) = \begin{cases} p - [1 - p] & \text{if} \quad 0 \le p < 1 \\ p & \text{if} \quad 1 \le p \le 2 \\ 0 & \text{if} \quad p > 2 \end{cases}$$

Non-price-setter:

- For given $p^* = 2$, firm 2 is also maximizing its profits by bidding $b_2 = \{0, 1, 2\}$; it is producing the max. it can w/o incurring in losses.
- Furthermore, given $b_1 = \{2, 2, 2\}$, firm 2 cannot profitably raise the price above $p^* = 2$ nor reduce it below $p^* = 2$.

Equilibrium:

- Hence, $b_1 = \{2, 2, 2\}$ and $b_2 = \{0, 1, 2\}$ is an equilibrium.
- By symmetry, $b_1 = \{2, 2, 2\}$ and $b_2 = \{0, 1, 2\}$ is also an equilibrium.
- There are many other, e.g. $b_i = \{2, 2, 3\}$ and $b_j = \{1, 1, 2\}$.
- ...but they are all price-equivalent!

Multiple Units: The General Model

Asymmetric bidding: price-setter versus non-price-setters

- One firm sets the price that maximizes its profits over its residual demand:

$$p_i^* \in \arg\max_p \pi_i^{PS}(p; b_{-i}) = p\left[D(p) - q_{-i}(p; b_{-i})\right] - C\left(q_i(p; b_{-i})\right)$$

- All other firms behave as price-takers (e.g. by bidding at MC).

Firms' deviation incentives:

- The **price-setter** cannot profitably deviate as it is already optimizing.
- The **non-price-setters** might find it profitable to deviate by raising the price:
  - The market price is increased at the expense of losing output. If the 'price effect' outweighs the 'quantity effect', such a deviation is profitable.
  - Deviating without increasing the price is unprofitable as the firm would then sell less at the same/lower price.

Multiple Units: The General Model

Equilibrium existence:

- Since deviating without increasing the price is unprofitable, the **highest-price candidate equilibrium always exists**.

Equilibrium multiplicity:

- More symmetry gives rise to more equilibrium outcomes...
- However, equilibrium outcomes also become more similar.
  - **Perfect symmetry**: there exist N equilibrium outcomes (depending on which firm sets the price) all of which result in the same equilibrium price.
  - **One large firm and a fringe of small firms**: there exists a unique equilibrium outcomes such that the large firm sets the price at its profit-max. level.
- **Intuition**: If firms are sufficiently symmetric, their profit-max. prices are similar. Hence, the non-price setters will not find it profitable to raise the price as it is already set close to their profit max. level.

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Long-lived Bids

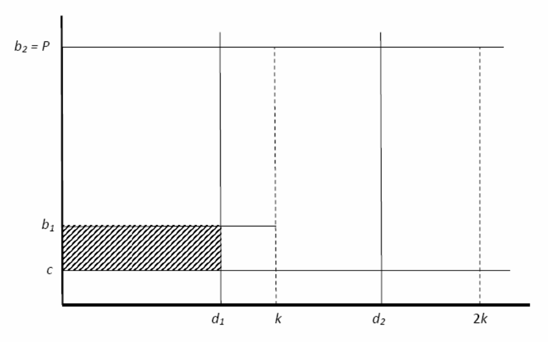
Bids remain fixed for an extended period

- ...over which demand varies in $\left[\underline{\theta}, \overline{\theta}\right]$ (equivalent to assuming the demand is uncertain)
- If $\underline{\theta} > k$ or if $\overline{\theta} < k$ the analysis remains the same as before.
- Demand uncertainty matters when both **high- and low-demand realizations occur with positive probability.**

Bidding incentives:

- There is a positive prob. that either firm will be marginal.
- This undermines incentives for strategic bidding, i.e., it reduces firms' profits.
- ...and **destroys any candidate pure strategy-equilibrium**:
  - **bidding high** max. profits if demand exceeds rival's capacity (high-demand).
  - **bidding low** max. profits if demand is below own's capacity (low-demand).

Bidding Incentives with Long-lived Bids



Mixed Strategy Equilibrium Under Long-lived Bids

- Suppose $\theta = \underline{\theta} < k$ with prob. ρ and $\theta = \overline{\theta} \in (k, 2k)$ with prob. $1 - \rho$.
- Let $F_i(b) = \Pr\{b_i \leq b\}$ denote the equilibrium mixed-strategy of firm i
- When bidding b, firm i's profits are:

$$\pi_i(b) = \rho\left[1 - F_j(b)\right] b\underline{\theta} + [1-\rho]\left[F_j(b) b\left[\overline{\theta} - k\right] + k\int_b^P v dF_j(v)\right]$$

- On $(\underline{b}, P)$, the net gain from raising the bid must be zero:

$$\rho\left[[1 - F(b)] - f(b)b\right] + [1-\rho]\left[F(b)\left[\overline{\theta} - k\right] - f(b)\, b\left[2k - \overline{\theta}\right]\right] = 0$$

- *Low demand* ρ: increasing the bid increases profits if the rival bids above, $[1 - F(b)]$, but reduces the prob. of bidding below the rival, $-f(b)b$.
- *High demand* $[1-\rho]$: increasing the bid increases profits if the rival bids below, $F(b)\left[\overline{\theta} - k\right]$, but reduces the prob. of selling at capacity instead of selling residual demand, $-f(b)\, b\left[k - \left(\overline{\theta} - k\right)\right]$.

Mixed Strategy Equilibrium Under Long-lived Bids

- Since profits must be the same for all bids in the support and no firm is playing a mass point at P, **equilibrium profits** must be

$$\overline{\pi} = \pi_i(P) = [1-\rho]\, P \left[\overline{\theta} - k\right]$$

- Expected profits under long-lived bids are lower as compared to when demand is variable but certain as

$$2\overline{\pi} = 2\,[1-\rho]\, P \left[\overline{\theta} - k\right] < [1-\rho]\, P\overline{\theta} \text{ given that } \overline{\theta} < 2k$$

  [note that with certain demand profits are zero with prob. ρ]
- Hence, **long-lived bids mitigate firms' market power**!

Discriminatory Auction

Fabra, von der Fehr and Harbord (Rand, 2006)

Suppose that bidders are **paid their own bid** (standard pricing rule).

Proposition

(i) (Low demand) if $\theta \leq k$, in the unique pure-strategy equilibrium the highest accepted price offer equals c and suppliers make no profits.

(ii) (High demand) if $\theta > k$, there does not exist a pure-strategy equilibrium. At the unique mixed-strategy equilibrium, each firm makes profits $[P - c]\,[\theta - k]$.

Comparison Across Auctions: A Tale of Two States

- **Low demand:**
  - Both auction formats are equivalent
- **High demand**
  - In the uniform-price auction all demand is paid at P whereas in the discriminatory auction the probability that the two firms bid at P is zero.
  - Hence, the **discriminatory auction induces lower prices**.
  - If **cost asymmetries** are taken into account, the comparison of **productive efficiency** across auctions depends on equilibrium selection in the uniform-price auction.

Collusion and Price-setting Rules

- Through the daily repetition of electricity auctions, firms may learn to coordinate their strategies, and hence compete less aggressively with each other over time, through tacit or explicit collusive agreements.

Factors affecting the sustainability of collusion in electricity markets

- **Repeated daily interaction**
    - Short detection lags which reduce the profitability of defection.
- **Publicly available information:** price bids and capacity declarations:
    - Allowing generators to directly monitor the bidding behaviour of their competitors, and hence to unambiguously detect - and possibly punish - deviations from collusive bidding strategies.
- Firms have **good information about each others' costs**:
    - Allowing for improved monitoring and improved coordination.
- **Small number of capacity-constrained bidders:**
    - The sustainability of collusion is in general, negatively correlated to the number of firms and the level of firms' capacities.

(A Primer on) Collusion

- For collusion to be sustainable the one-shot deviation gain need not exceed the net-present value of the losses from cheating:

$$\left[\pi^d - \pi^c\right] \leq \frac{\delta}{1-\delta}\left[\pi^c - \pi^p\right]$$

- For given collusive profits π^c, collusion will be more easily sustainable:
  - the smaller deviation profits π^d;
  - the smaller punishment profits π^p.

How does **market design** affect the **sustainability of collusion**?

Collusion: Uniform versus Discriminatory

Fabra (JIE, 2003): The uniform-price auction facilitates collusion

- N **capacity-constrained** firms interact in an **infinitely repeated** game.
- **Demand** $D(p)$ is downward-sloping, $D'(p) < 0$.
- **Marginal costs** are normalized to zero, $c = 0$.
- Monopoly and residual-monopoly prices:

$$
\begin{aligned}
p^m &= \arg\max_p \pi^m = pD(p) \\
p^r &= \arg\max_p \pi^r = p\left[D(p) - k\right]
\end{aligned}
$$

- Assume (just for the presentation): $D(p^m)/2 < k < D(p^m)$.

Collusion: Uniform versus Discriminatory

- The **optimal punishment** is **equally severe** under the uniform-price and discriminatory auction:
  - The deviant's profits can be driven down to its minmax level (punishment profits *as if* rivals sold at capacity).
- However, **deviation profits are weaker in the uniform-price auction**.
  - In the uniform-price auction, the low bid is pay-off irrelevant. The low-bid can thus be used to reduce its rival's deviation incentives below those at the discriminatory auction, in which both bids are pay-off relevant.

Deviation incentives: Uniform versus Discriminatory

Discriminatory auction

- Firms collude on symmetric bid profiles (p^m, p^m)
- The optimal deviation is to slightly undercut the rival: $\left[\pi^d - \pi^c\right] = \pi^m/2$.

Uniform-price auction

- Firms can collude on asymmetric bid profiles $(0, p^m)$ and jointly obtain monopoly profits
- They rotate their bids: firm 1 (firm 2) bids p^m in odd (even) periods
- Only the firm that bids at p^m has incentives to deviate to set p^r:

$$\left[\pi_t^d - \pi_t^c\right] = \pi^r - p^m \left[D\left(p^m\right) - k\right] < \pi^m/2 \text{ as } \pi^m > 2\pi^r$$

- Further, if the firm does not deviate, it is rewarded in the following period:

$$\pi_{t+1}^c = kp^m > \pi^m/2.$$

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(Horizontal) Market Structure

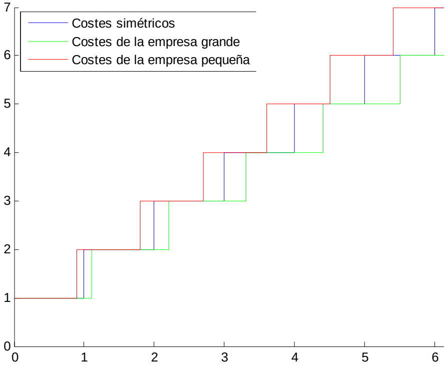
- Where as market design is certainly important, market structure also affects market performance.
- Indeed, when assessing the competitiveness of an industry, authorities typically resort to market concentration measures.
- What do our models of electricity market competition tell us about the effects of (horizontal) market structure on equilibrium outcomes?

Numerical Solutions

We use the **multi-unit auction model** to predict equilibrium outcomes in a market with the following features:

- $N = 2$ firms
- 200 production units (2 units for each cost level).
  - Units $2k - 1$ and $2k$ have marginal costs k, for $k = 1, .., 100$.
  - Each firm has one unit with marginal costs k; all its units have equal capacity.
  - Firm 2's capacity is s times 1's capacity, for $s \in (0, 0.5]$.
- Note: asymmetries in size imply asymmetries in costs.

Cost Curves


Costes simétricos
Costes de la empresa grande
Costes de la empresa pequeña
0
1
2
3
4
5
6
7
0
1
2
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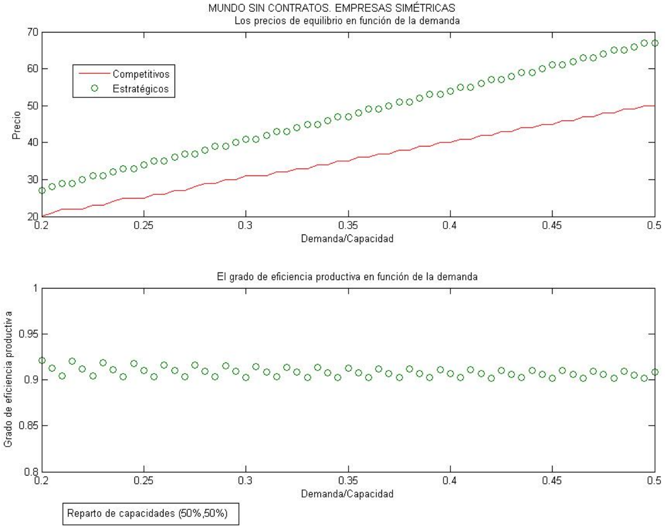
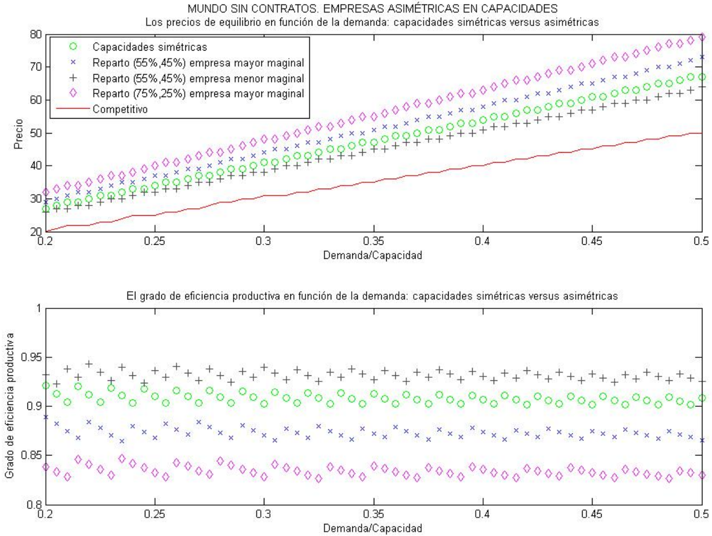
4
5
6

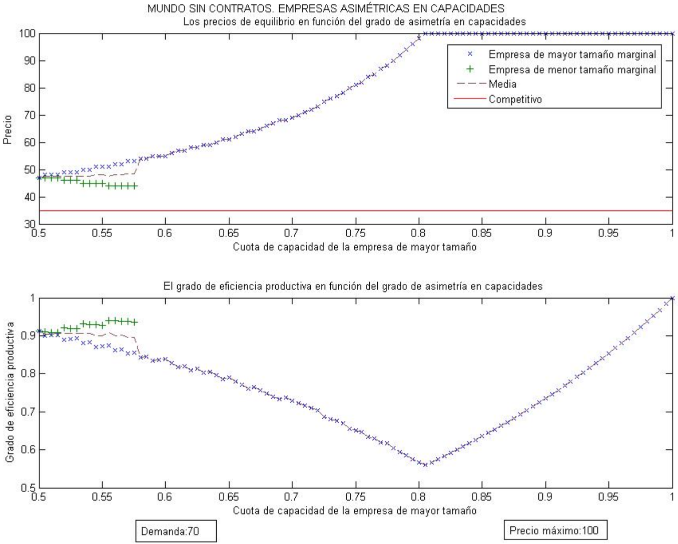
Symmetric Firms



Symmetric Firms vs. Asymmetric Firms



The Effect of Firms' Asymmetries on Equilibrium Prices



Discussion

Market concentration has a **non-monotonic effect** on the **price-cost mark-up:**

+ Above a certain threshold, **only the capacity of the large firm matters** (i.e. whenever there exists a unique equilibrium in which the large firm sets the price).
+ As the large firm becomes larger, the price-cost mark-up increases.
= Also, the **degree of concentration among the small firms** is irrelevant.
− However, if a **merger between the smaller competitors** gives rise to a new equilibrium in which the merged entity sets the price, the associated increase in concentration might be **pro-competitive.**

Need to use specific models of competition in electricity markets in order to predict the link between market structure and market performance

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Discussion

- But....
- When assessing the performance of different market designs we have taken market structure as given
- However, in the **long-run**, market structure and investment incentives depend on market rules...
- ...and the effectiveness of market rules depends on the market structure.
  - e.g. under monopoly or in atomized markets all auction rules are equivalent!

What came first: the chicken or the egg?